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Arch-support foot-orthoses normalize dynamic in-shoe foot pressure distribution in medial tibial stress syndrome

Aynollah Naderi[1], Hans Degens*,[2,3] & Ainollah Sakinepoor[4]

[1]Department of Health and Corrective Exercise, School of Physical Education and Sport Sciences, Shahrood University of Technology, Shahrood, Semnan, Iran; [2]School of Healthcare Science; Manchester Metropolitan University, UK; [3]Institute of Sport Science and Innovations, Lithuanian Sports University, Lithuania; [4]Department of Physical Education and Sport Science, Faculty of Human Science Borujerd Branch, Islamic Azad University Borujerd, Iran

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Address for correspondence:

Hans Degens

School of Healthcare Science

Manchester Metropolitan University

John Dalton Building; Chester Street

Manchester M1 5GD

United Kingdom

Phone: +44.161.247.5686

E-mail: h.degens@mmu.ac.uk

Abstract

Excessive foot pronation during gait is a risk factor in medial tibial stress syndrome (MTSS). Arch-support foot-orthoses are commonly used to manage overpronation, but it is unknown whether it is effective to manage MTSS. The present study investigated the effects of bilateral foot orthoses during running on dynamic foot-pressure distribution patterns in recreational runners with MTSS. Fifty novice (started within the last 4 months) runners diagnosed with MTSS (20.7 ± 2.2 years; 71.1 ± 8.6 kg; 1.78 ± 0.07 m; mean ± SD) and 50 anthropometrically-matched healthy novice runners (21.9 ± 2.4 years; 71.4 ± 8.8 kg; 1.73 ± 0.07 m) participated in this study. The dynamic foot-pressure distribution during running with and without bilateral arch-support foot-orthoses was measured using pedobarography. MTSS novice runners have more medially directed pressures during the touchdown phase of the forefoot flat ($p=0.009$) and heel off ($p=0.009$), and a lateral pressure distribution during forefoot push-off phase ($p=0.007$) during running than healthy runners. When using the arch-support foot-orthoses the foot-pressure distribution during all phases was not significantly different from that seen in participants without MTSS. These findings indicate that during running the medial shift of foot pressures during the loading response phase and the lateral shift during the propulsion phase of foot roll-over in MTSS are effectively corrected by using arch-support foot-orthoses. The use of such arch-support orthoses may thus be an effective tool to normalize foot-pressure distribution patterns during running, indicating the potential to treat and prevent MTSS in recreational runners.

Keywords: Overuse injuries, running, foot biomechanics, orthotic, shoe inserts

Highlights:

- ✓ Arch-support foot-orthoses decrease total contact time in runners with medial tibial stress syndrome (MTSS)
- ✓ The absolute impulse in the midfoot area decreased and the peak pressure and absolute impulse in the fifth metatarsal region increased in the MTSS participants when using arch-support foot-orthoses
- ✓ During the use of arch-support foot-orthoses, foot pressure was shifted laterally at forefoot flat and heel off, and the lateral foot pressure displacement was decreased during forefoot push-off phase.
- ✓ The use of arch-support foot-orthoses normalized the foot-pressure distribution patterns during running, indicating the potential to treat and prevent MTSS in runners.

Introduction

In recent decades, the growing interest in disease prevention has increased the public participation in sports (Haskell et al., 2007). Given the 19.4-79.3% prevalence of lower extremity sports-related injuries in distance runners (Gallo, Plakke, & Silvis, 2012; Gent et al., 2007), the increased participation in running will inevitably increase the number of such injuries in the population as whole.

The lower leg is one of the most common places of injury in runners (Gallo et al., 2012). Medial tibial stress syndrome (MTSS) accounts for up to 35% of all cases of exercise-induced leg pains (Moen, Tol, Weir, Steunebrink, & De Winter, 2009) and affects 10.7% and 16.8% of male and female recreational runners, respectively (Clement, Taunton, Smart, & McNicol, 1981). MTSS is defined as exercise-induced pain along the posteromedial border of the distal two-thirds of the tibia that occurs prior to, during, or after activity, and is provoked by palpation of this area (Winters, Bon, Bijvoet, Bakker, & Moen, 2017). Particularly novice recreational runners are at risk to develop MTSS (Buist, Bredeweg, Lemmink, Mechelen, & Diercks, 2010).

MTSS reduces the ability to participate in physical activity and can incur financial costs associated with treatment and lost productivity (Parkkari, Kujala, & Kannus, 2001). Left untreated, the condition may progress to a full stress fracture (Mokha, Winters, Kostishak, Valovich McLeod, & Welch, 2014; Winters et al., 2013) that needs extended periods (4 to 8 weeks) for recovery. There is thus an urgent need to treat and prevent MTSS in physically active people (Mokha et al., 2014; Thacker, Gilchrist, Stroup, & Kimsey, 2002; Winters et al., 2013).

There is strong evidence that the navicular drop and foot pronation during gait are increased in the individuals with MTSS (Bennett et al., 2001; Tweed, Campbell, & Avil, 2008; Willems, Witvrouw, De Cock, & De Clercq, 2007), suggesting that they are risk factors for development of MTSS. It is assumed that pronation during the touchdown phase of running helps to damp ground reaction forces in the lower extremity as it prolongs deceleration and consequently the magnitude of these forces (Perry & Lafortune, 1995; Pratt, 1989). With excessive pronation, however, the subtalar joint is already at such a position that that the inward roll-over absorption mechanism is limited and thus the lower extremity is exposed to higher ground reaction forces (Perry & Lafortune, 1995; Sharma, Golby, Greeves, & Spears, 2011). This in turn may cause problems associated with excessive stress, such as MTSS (bone stress reaction theory) (Tweed et al., 2008; Sharma et al., 2011).

In addition, excessive pronation is associated with more and longer eccentric activity of extrinsic anti-pronatory muscles (Murley, Menz, & Landorf, 2009) that leads to increased strain to the medial border of the tibia and its periosteum, and in turn symptoms of MTSS (tibial-fascial traction theory) (Bouche & Johnson, 2007). In runners with excessive foot pronation, increased foot invertor and plantarflexor muscle activity (Murley et al., 2009) can lead to early muscle fatigue. The fatigued muscles absorb less force and consequently more of the force has to be absorbed proximally by the tendo-periosteum and bone (Mizrahi, Verbitsky, Isakov, & Daily, 2000), which can be an additional cause of MTSS. Therefore, management of excessive pronation is likely to be an effective therapeutic option to treat and/or prevent MTSS.

Although several treatment methods have been successful in pain relief (Galbraith & Lavallee, 2009; Newman, Waddington, & Adams, 2017; Thacker et al., 2002), none of them have been effective in managing the cause of MTSS (Winters et al., 2013). However, some techniques, such as foot orthoses, and strengthening and stretching exercises (Moen et al., 2009; Rome, Handoll, & Ashford, 2005) that modify lower limb biomechanics can be expected to effectively manage and/or prevent MTSS.

Physicians and physiotherapists often recommend foot orthoses for patients with foot/lower-leg problems. Excessive foot pronation is an important risk factor for lower leg problems and orthoses can help normalizing lower extremity kinematics, such as decreased foot pronation and tibial internal rotation (Hsu et al., 2014; McPoil & Cornwall, 2000). Foot orthoses can also effectively alter muscle activity patterns (Murley, Landorf, & Menz, 2010), and help to normalize the dynamic foot-pressure distribution (Lo, Wong, Yick, Ng, & Yip, 2016) during gait and running. Although the beneficial effect of foot orthoses on dynamic foot-pressure distribution has been shown in overuse injuries (Bonanno, Landorf, Munteanu, Murley, & Menz, 2017), its effect during running in runners with MTSS has not been evaluated.

Therefore, the objectives of the present study were to assess 1) the difference between the foot-pressure distribution in novice runners with and without MTSS and 2) the effects of arch-support foot-orthoses on foot-pressure distribution in runners with MTSS. It was hypothesized that there is a difference between the pattern of foot-pressure distribution in healthy control novice runners and those suffering from MTSS that will be normalized by the use of arch-support orthoses.

Methods

Participants

Hundred men who all started running within the last 4 months participated in the study; 50 runners with MTSS and 50 anthropometrically-matched healthy runners. A group of 180 novice recreational runners suspected to suffer from MTSS were screened, and 50 people met the MTSS inclusion criteria. The inclusion criteria were: pain was induced by exercise and lasted for hours or days after exercise, pain was located in the distal half of the posteromedial tibia and had to cover an area with a length of more than 5 cm (a pain site less than 5 cm long is usually caused by a stress fracture (Yates & White, 2004)), symptoms had to be present for at least 3 weeks and palpation of the tibial posteromedial border induced discomfort that was restricted to this area (Edwards, Wright, & Hartman, 2005; Hubbard, Carpenter, & Cordova, 2009; Yates & White, 2004). A healthcare sports physiotherapist confirmed the diagnosis. Other inclusion criteria were: age between 18 and 25 years, taking up running in the last 4 months, running less than 3 times per week for <45 min and/or <10 km per session, but having the ability to run at a self-selected speed for approximately 30 min and/or 5 km at a time, not being overweight (BMI > 30 $kg \cdot m^{-2}$ excluded) and being able to provide informed, written consent.

Participants were excluded if they had a history of paresthesia, symptoms indicative of other causes of exercise-induced leg pain (such as tibial stress fracture and chronic compartment syndrome), used arch-support orthoses, received physiotherapy in the previous 6 months, currently used anti-inflammatory medication, had a history of lower-limb traumatic injury or surgery within the last 6 months, hallux valgus, or an obvious leg-length discrepancy.
In our study, healthy participants had no flat feet.

All participants lived in (**Blinded**) and were recruited through presentations in the local community between November 2016 and May 2017. All participants provided written informed consent. All procedures were approved by the Institution Review Board of (**Blinded**) and were in accordance with the Declaration of Helsinki.

Procedure

All participants visited the laboratory twice. The first visit was to become familiar with the laboratory setting and testing procedures, and various baseline parameters were measured. The body mass was measured on a digital scale (SECA 760, Vogel & Halke GmbH & Co., Hamburg, Germany) to the nearest 0.1 kg and height was measured to the nearest 0.1 cm. The body mass index (BMI) was calculated as body mass·height^{-2} (kg·m^{-2}) (World Health Organization [WHO], 2010). The side of symptoms, number of days with symptoms, and running volume were recorded. To assess the pain severity a hand-held dial Pressure Algometer (Baseline ® Gauge Model 12-0304, Fabrication Enterprises Inc., New York, USA) was used to exert 5 kg of pressure on the posteromedial tibial border (the most tender point of the lower leg) and evaluated using a visual analog scale (VAS).

Foot postures was evaluated by the foot posture index (FPI-6) that includes six criteria (talar head palpation, supra and infra lateral malleoli curvature, calcaneal frontal plane position, prominence in region of talonavicular joint, congruence of medial longitudinal arch, and abduction/adduction of forefoot on rearfoot). Each of these criteria is scored from -2 to 2. The foot posture is considered normal (0 to+5 score), pronated (+6 to +9 score), highly pronated foot (+10< score), supinated foot (-1 to -4 score), or highly supinated (-5 to -12) (Redmond, Crane, & Menz, 2008).

At the second visit, the dynamic pressure distribution during running trials was assessed using a force plate (RsScan International, Paal, Belgium, 40×100 cm, 8192 sensors, 253 Hz) that was placed in the middle of a 12-m-long runway. The RSscan system was calibrated according to the guidelines of the manufacturer before each session. The reliability of the RSscan system for the temporal plantar pressure variables of foot roll-over during running have been previously reported (ICC.0.75) (De Cock, De Clercq, Willems, & Witvrouw, 2005). Here we found that the trial-to-trial consistency in a sample group of 15 MTSS, and the ICC between three trials of peak pressure and absolute impulse of 10 anatomical areas ranged from 0.73 to 0.98.

To familiarize with the test procedures, the participant performed a number of practice trials. After familiarization, runners with MTSS performed three leg-stance phase tests for each of the affected legs (some participants had bilateral MTSS) before and during the use of arch-support orthoses. During these trials, the participants wore the running shoes they used for recreational running and run at a speed of 3.3 $m \cdot s^{-1} \pm 5\%$ over the runway (De Cock et al., 2005; Willems et al., 2007), monitored by two sets of infrared photocells. In each trial, the participants were instructed to run to the end of the runway. Trials were considered valid if the participant had a heel strike pattern, complete foot contact and made no adjustment in step length to make contact with the pressure plate.

The software (Footscan software 7.0 Gait 2nd Generation, RsScan International, Paal, Belgium) automatically divided the foot into ten anatomical zones that were, if necessary, manually controlled and adapted by the researcher: medial heel (HM), lateral heel (HL), midfoot (MF), metatarsal areas I–V (M1, M2, M3, M4 and M5), the hallux (T1) and toes 2–5 (T2–5) (De Cock et al., 2005; Willems et al., 2007).

For those regions, temporal data (i.e. moment the regions make contact and moments of loss of contact), peak pressure data and absolute impulse were calculated from the duration of each phase by the RScan software. Five distinct instants of foot rollover were determined to divide the stance period into four phases (Blanc, Balmer, Landis, & Vingerhoets, 1999): first foot contact (FFC: the instant the foot made first contact with the pressure plate), first metatarsal contact (FMC: the instant one of the metatarsal heads contacted the pressure plate), forefoot flat (FFF: the first instant all metatarsal heads made contact with the pressure plate), heel off (HO: the instant the heel loses contact with the pressure plate) and last foot contact (LFC: the last contact of the foot on the pressure plate) (De Cock et al., 2005; Willems, De Ridder, & Roosen, 2012). Based on these instants, total foot contact-time (TFCT) was divided into four phases: initial contact phase (ICP: FFC→ FMC), forefoot contact phase (FFCP: FMC → FFF), foot flat phase (FFP: FFF→ HO) and forefoot push-off phase (FFPOP: HO→ LFC).

Medio-lateral pressure ratios [(T1 + M1 + HM) - (HL + M3 + M4 + M5)]×100/(T1 + M1 +M3 + M4 + M5 + HM + HL) were calculated at these five instants of foot contact. The mean of this ratio was calculated for each phase (ICP, FFCP, FFP, and FFPOP). The X-component (medio-lateral) and Y-component (anterior-posterior) of the center of pressure (COP) scaled to the foot width and length, respectively, were analyzed. The positioning and displacements of the components were calculated at the five instants and in the four phases (De Cock et al., 2005; Willems et al., 2007). The mean of three trails was taken for analysis (De Cock et al., 2005).

Foot orthoses

Arch-support full-length foot-orthoses (Model; LX-0701-1, Longxin, Industrial Co., Ltd, Guangdong, China) were fit in the shoes using double-sided tape. Foot orthoses were made from 4-mm thick polypropylene of medium density (Durometer Shore 50A) with an approximately 15-mm high heel cup and a 25-mm peak-height arch-support. The orthoses were reusable and each participant was provided by arch-support orthoses in both left and right shoes. Participants were informed of the insert condition and that the objective of the study was to evaluate the efficacy of shoe inserts to diminish MTSS.

Statistical analysis

SPSS statistical software (version 18.0, SPSS Inc., Chicago, IL, USA) was used to perform all statistical analyses. A priori power analysis (G*power), based on previous data, revealed that to detect large effect sizes (Impulse M, Cohen's d=0.46 and medio-lateral pressure ratios during the forefoot contact phase (FFCP), Cohen's d=0.51) at a statistical power of 0.80 and an effect size of 0.70 with a 2-tailed significance level of 0.05, 50 participants per group were required. The Shapiro-Wilk test was used to assess normality. Independent t-tests (if the distribution of the data was normal) or Man-Whitney U-tests (if the data were not normally distributed) were used to compare pre- and post-test values in the MTSS group with those in the healthy control group. Paired t-tests (if the distribution of the data was normal) or a Wilcoxon signed-rank test (if the data were not normally distributed) were used to compare pre- and post-test values in the MTSS group. The effect size Cohen's d (ES) was calculated for all variables between groups. Thresholds for small, moderate and large effects were 0.20, 0.50 and 0.80, respectively (Cohen, 1992). For all statistical procedures, the significance level was set at $p<0.05$. Data is presented as mean ± SD.

Results

The anthropometric data of the MTSS and healthy control groups are presented in table 1. There were no significant differences between groups with respect to age, height, mass and BMI ($p>0.05$). Sessions, duration, and distance run per week did also not differ significantly between the two groups (Table 1). Only the MTSS participants reported pain severity and a history of pain. The foot posture index score for the target side in the MTSS participants was larger than that in healthy controls ($p\leq0.05$), confirming foot over-pronation.

Although total contact time was longer (p=0.006; ES=1.12), the hallux (T1) lost contact sooner (p=0.04; ES=0.86) in the MTSS than in the healthy control group (Table 2). The total contact time decreased in MTSS participants when using arch-support foot-orthoses (p=0.013;

ES=0.99) and became similar to that seen in the healthy control participants ($p>0.05$). There were no significant differences between groups for any other parameter (Table 2).

The peak pressure and absolute impulse in the mid-foot region were higher ($p=0.008$; ES=1.03 and $p=0.002$; ES=1.0; respectively), whereas peak pressure and absolute impulse underneath the M5 region were lower ($p=0.003$; ES=1.22 and $p=0.009$; ES=0.99; respectively) in the MTSS than in the healthy control group (Table 3). The absolute impulse in the mid foot area decreased ($p=0.02$; ES=1.0) and the peak pressure and absolute impulse in the M5 region increased in runners with MTSS when using arch-support foot-orthoses ($p=0.03$; ES=0.99 and $p=0.006$; ES=1.04; respectively), resulting in similar pressure distributions as seen in the healthy control group ($p>0.05$).

The pressure distribution was more medially directed at FFF and HO ($p=0.009$; ES=0.99 and $p=0.01$; ES=0.99; respectively) in the MTSS than in the healthy control group (Fig. 1A). Furthermore, medio-lateral ratios showed more pressure displacement from lateral to medial during FFCP ($p=0.02$) and more pressure displacement from medial to lateral during FFPOP ($p=0.007$) in the MTSS than in the healthy control group. During the use of arch-support foot-orthoses, the pressure distribution was shifted laterally at FFF and HO ($p=0.004$ and $p=0.006$). The pressure displacement was shifted from lateral to medial during FFCP ($p=0.02$) and from medial to lateral during FFPOP ($p=0.001$) for MTSS when using arch-support foot-orthoses (Fig. 1A), making them similar to the pressure distributions seen in control participants ($p>0.05$).

The X-component of the COP was situated more medially at FFF ($p=0.002$; ES=1.25) and was displaced to the lateral side during FFPOP ($p=0.001$; ES=1.35) in the MTSS in comparison to the control group. During the use of arch-support foot-orthoses, the X-component of the COP was shifted laterally at FFF (P=0.001; ES=1.38) and the lateral COP displacement was decreased during FFPOP (p=0.001; ES=1.0) (Fig. 1B), making them comparable to that seen in the control group (p>0.05). No significant differences were found for the Y-component of the COP (Fig. 1C).

Discussion

Abnormal foot biomechanics is considered an important intrinsic risk factor for the development of MTSS. Despite significant advances in the understanding of foot and ankle biomechanics, the relationship between abnormal foot biomechanics and overuse injuries is still not well known. To date, no research has been done on the effects of foot orthoses on gait variables in runners with MTSS. The main observation of the present study is that the dynamic pattern of foot-pressure distribution differs between healthy controls and participants suffering from MTSS. More specifically, there was: 1) longer TFCT than that seen in healthy controls, indicating a prolonged foot pronation; 2) less lateral foot roll-over during initial and mid stance, resulting in higher pressures and loading underneath the medial side of the foot; and 3) a lateral shift of COP during the late stance, so that the propulsion phase of foot roll-over occurs through the smaller toes. All these abnormalities were abolished during the use of arch-support orthoses and this suggests that MTSS is indeed associated with abnormal foot biomechanics that may well be restored during the use of arch-support foot-orthoses.

Foot-pressure distribution in MTSS

TFCT during running was longer in MTSS participants than in healthy controls. A possible explanation for the longer stance phase can be the longer duration of foot pronation as has been reported previously for MTSS (Sharma et al., 2011). This longer TFCT and pronation duration can be intrinsic risk factors for lower-leg pain (Willems et al., 2007). Previous studies (Bennett et al., 2001; Hubbard et al., 2009; Tweed et al., 2008; Yates & White, 2004) have indeed found that prolonged pronation is an intrinsic risk factor of MTSS. According to the 'traction theory' this increased risk of MTSS with prolonged pronation is due to a longer eccentric contraction of the foot plantar-flexor and -invertor muscles (Murley et al., 2009) that increase the bending force on the insertion area of these muscles on the fascia-periosteum of the tibia (Tweed et al., 2008). Prolonged use and excessive load on these muscles during exercise can also cause an earlier onset of muscle fatigue that reduces the ability of these muscles to absorb the ground reaction forces and hence increases the stress that has to be absorbed by the bone (exacerbated bone stress reaction) (Mizrahi et al., 2000). These theories are not mutually exclusive and it is likely that both explain the development of MTSS.

In MTSS the peak pressure and impulse were lower underneath the 5th metatarsal, consistent with the reported association with exercise-induced lower-leg pain (Willems et al., 2007). The higher pressures underneath the midfoot region are consistent with studies that reported excessive pronation in MTSS (Hubbard et al., 2009; Yates & White, 2004). Furthermore, the pressure distribution during FFCP, at the HO and FFF instants, and the X-component of the COP to the heel-M2 axis of the foot during the FFF were more medially directed in MTSS as has been reported previously for military recruits with tibial stress fracture (Creaby & Dixon, 2008). That this may be the case is supported by the observation of Willems et al. (2007) who showed that participants with exercise-related lower-leg pain are more likely to over pronate than healthy controls.

In our study, the pressure distribution and the X-component of the COP to the heel-M2 axis of the foot during FFPOP were more laterally directed in MTSS compared to healthy control participants. These results can indicate that final foot roll-over in the MTSS participants did not occur through the hallux, as in healthy control participants, but rather more laterally through the smaller toes. This is similar to the more lateral forefoot push-off across the small toes in the athletes with lower-leg pain (Willems et al., 2007) and ankle inversion sprain (De Cock et al., 2005). This can be explained by reduced support in the first metatarsophalial joint in MTSS that due to excessive pronation may have a limited range of motion (Aquino & Payne, 2001). These findings support an association between a defective windlass mechanism and a foot that demonstrates an excessive amount or duration of pronation, because more lateral forefoot push-off across the small toes would render the windlass mechanism ineffective (Aquino & Payne, 2001).

The effect of foot orthoses on foot-pressure distribution in MTSS

Foot-arch support is often recommended to reduce the incidence of overuse injuries (Bonanno et al., 2017) through optimizing lower extremity biomechanics, neuromuscular adaptations, reduction of muscle fatigue and improving the foot-pressure distribution (Bonanno et al., 2017). In our study, the use of arch-support foot-orthoses resulted in a reduction of TFCT to that seen in healthy controls. A lower TFCT leads to a reduced amount and duration of the activity of the anti-pronatory and plantartflexor muscles to support the arch. This in turn reduces the eccentric contraction time and consequent bending force on the tibia, and/or late fatigue of these muscles, thus addressing both causes of MTSS suggested by the traction and bone stress reaction theories. In support of such a mechanism is the observation that arch-support orthoses in patients with pronated feet was indeed associated with a reduced amount of activity of some anti-pronatory and plantartflexor muscles during walking (Lo et al., 2016; Murley et al., 2010) and hence decreased demand on these muscles to support the arch.

During the use of arch-support foot-orthoses, the center of pressure during the FFPOP shifted medially and became similar to that seen in healthy control participants. One factor that is thought to contribute to this medial shift is the increase in aponeurotic tension that would tether the plantar plate of the first metatarsophalangeal joint and thereby stabilize this joint (Aquino & Payne, 2001). Thus, the push off occurs through the first metatarsophalangeal joint and the final point of contact is the hallux similar to the healthy control participants. The use of arch-support foot-orthoses in the MTSS participants also resulted in a reduced peak pressure and impulse rate underneath the midfoot to values in the normal range seen in the healthy control group. In addition, the abnormal distribution of foot pressure during the FFCP, and at the HO and FFF instants became similar to that of the control participants. Such a result was also observed in runners with lower extremity overuse injuries (Scranton, Pedegana, & Whitesel, 1982). In addition, previous studies have reported that applying arch-support foot-orthoses resulted in a decreased force, impulse and time-to-peak ground-reaction force in the midfoot during the stance phase of gait in people with excessive foot pronation (Farahpour, Jafarnezhad, Damavandi, Bakhtiari, & Allard, 2016). It thus appears that the reduction of foot pronation with foot orthoses (Hsu et al., 2014) may well be an effective means to restore and optimize lower limb biomechanics, and a normal dynamic foot-pressure distribution.

Limitations and future studies

One limitation is that this study did not assess muscle activities and three-dimensional movement of the lower extremity during gait, which could bring additional insight in the intrinsic risk factors of MTSS. Another limitation is that we did not assess the impact of foot orthoses on pain, the main reason of a visit to the doctor, during activity and/or post-exercise in runners with MTSS. While the current study, to our knowledge, is the first study that provided evidence that arch-support foot-orthoses reduce the potentially injurious effects of gait abnormality, we do not provide direct evidence that the arch-support foot-orthoses can be used to prevent or treat MTSS. To elucidate this, prospective studies are required to examine the long-term preventative effects of arch-support foot orthoses on developments of MTSS.

Conclusion

We observed that the dynamic pattern of foot-pressure distribution differed between healthy runners and runners suffering from MTSS due to prolonged foot pronation. This foot-pressure distribution pattern in runners with MTSS was restored during the use of foot orthoses and indicates that arch-support foot-orthoses could be useful in both preventing and managing MTSS, but future prospective studies should be performed to confirm this.

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No potential conflict of interest was reported by the authors.

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Table 1.

Participant characteristics

Variables	MTSSG (n=50) Mean ± SD	HCG (n=50) Mean ± SD	t	p-value
Age (y)	21.9 ± 2.4	21.1 ± 2.5	1.0	0.37
Mass (kg)	77.0 ± 4.4	73.6 ± 6.5	1.7	0.11
Height (cm)	179 ± 6	176 ± 5	1.4	0.16
Body mass index ($kg \cdot m^{-2}$)	23.8 ± 1.6	24.2 ± 1.5	0.60	0.6
Foot Posture Index score (target side)	6.8± 1.1	2.7± 2.9	6.5	0.001*
Supinated, n (%)	2 (4)	3 (6)		
Normal, n (%)	12 (24)	39 (78)	32.3	0.001*
Pronated, n (%)	34 (72)	8 (16)		
Side affected, n (left/right/bilateral)	3/32/15	-	-	-
Target side, n (%)(left/right)	15(30)/35(70)	15(30)/35(70)	-	-
Pain severity (mm)	62.1 ± 8.7	-	-	-
Pain history(week)	8.9 ± 2.30	-	-	-
Number of running sessions per week	3.8 ± 0.8	3.7 ± 0.7	0.25	0.8
Minutes run per week	120 ± 20	115 ± 17	0.63	0.5
Distance run per week (km)	15.7 ± 2.7	15.2 ± 2.6	0.51	0.6

Abbreviations: MTSSG, medial tibial stress syndrome group; HCG, healthy control group

Note. *, significant difference

Table 2. Total contact time, time of first metatarsal contact, forefoot flat and heel off, relative first contact time and relative end of contact to total foot contact for the ten anatomical areas in the group with medial tibial stress syndrome before (BFO) and during (DFO) foot orthoses and the healthy control group (HCG).

Variables	BFO (n=50) Mean± SD (95% CI)	DFO (n=50) Mean± SD (95% CI)	HCG (n=50) Mean± SD (95% CI)	t test / Wilcoxon (P-value)	t test /Mann–Whitney (p-value)	
					HCG W BFO	HCG W DFO
Total contact time (ms)	241 ± 39 (230 to 251.8)	211 ±18 (206 to 217)	206 ± 21 (206 to 217)	0.013*	0.006$	0.52
First meta-tarsal contact (ms)#	25.7 ± 12.3 (22.4 to 29.1)	25.5 ± 11.0 (22.5 to 28.5)	25.9 ± 12.3 (22.5 to 29.3)	0.94	0.94	0.89
Forefoot flat (ms)	46.9 ± 13.4 (43.2 to 50.6)	46.5 ± 14.4 (42.5 to 50.5)	47.8 ± 13.3 (44.1 to 51.5)	0.91	0.86	0.79
Heel off (ms)	109 ± 20 (104 to 114)	110 ± 22 (104 to 116)	106 ± 12 (103 to 109)	0.92	0.59	0.52
First contact T_1 (%)	32.1 ± 5.1 (30.7 to 33.5)	31.9 ± 6.4 (30.2 to 33.6)	32.3 ± 6.0 (30.7 to 33.9)	0.93	0.95	0.87
First contact T_{2-5}(%)	25.3 ± 5.5 (23.8 to 26.8)	26.6 ± 7.8 (24.5 to 28.7)	26.5 ± 5.9 (24.9 to 28.1)	0.65	0.55	0.97
First contact M_1 (%)	20.2 ± 4.7 (17.9 to 21.5)	20.1 ± 5.5 (18.6 to 21.6)	20.2 ± 5.0 (18.8 to 21.6)	0.94	0.98	0.94
First contact M_2 (%)	16.9 ± 2.3 (16.1 to 17.3)	16.7 ± 3.4 (15.8 to 17.6)	17.3 ± 3.4 (16.7 to 17.9)	0.87	0.71	0.63
First contact M_3 (%)	17.3±2.0	16.1 ± 3.1	16.8 ± 3.2	0.27	0.59	0.56

	(16.8 to 17.8)	(15.2 to 16.9)	(14.9 to 17.6)			
First contact M_4 (%)[#]	14.5±2.5 (13.9 to 15.1)	14.5 ± 3.0 (13.7 to 15.3)	14.9 ± 3.0 (14.1 to 15.7)	0.96	0.69	0.76
First contact M_5 (%)	11.4 ± 3.0 (10.6 to 12.2)	12.0 ± 3.0 (11.2 to 12.8)	11.3 ± 2.9 (10.5 to 12.1)	0.67	0.92	0.52
First contact Mid foot (%)[#]	4.5± 1.7 (4.1 to 4.9)	5.1± 1.8 (4.6 to 5.6)	4.2 ± 1.9 (3.7 to 4.7)	0.52	0.60	0.18
First contact H_M (%)	1.02 ± 0.01 (1.01 to 1.03)	1.01 ± 0.01 (1.0 to 1.02)	1.01 ± 0.01 (1.0 to 1.02)	0.82	0.96	0.90
First contact H_L (%)	0.03 ± 0.01 (0.02 to 0.04)	0.03 ± 0.01 (0.02 to 0.04)	0.04 ± 0.01 (0.03 to 0.04)	0.78	0.13	0.06
End contact T_1 (%)	97.9 ± 1.8 (97.4 to 98.4)	98.00 ± 2.8 (97.2 to 98.8)	99.4 ± 1.7 (99.0 to 99.8)	0.94	0.04[$]	0.1
End contact T_{2-5}(%)	98.7 ± 1.3 (98.3 to 99.1)	96.1 ± 2.2 (95.5 to 96.7)	97.2 ± 3.0 (96.4 to 98.0)	0.001*	0.06	0.4
End contact M_1 (%)	88.2 ± 2.6 (87.5 to 88.9)	87.9 ± 3.5 (86.9 to 88.9)	87.4 ± 4.2 (86.2 to 88.6)	0.75	0.54	0.74
End contact M_2 (%)	89.9 ± 3.2 (89.0 to 90.8)	89.3 ± 3.3 (88.4 to 90.2)	89.2 ± 3.8 (88.1 to 90.3)	0.58	0.57	0.92
End contact M_3 (%)	87.9 ± 2.9 (87.1 to 88.7)	87.1 ± 3.8 (86.0 to 88.2)	87.3 ± 4.5 (86.1 to 88.5)	0.51	0.66	0.89
End contact M_4 (%)	83.3 ± 5.1 (81.9 to 84.7)	82.7 ± 4.5 (81.5 to 83.9)	83.8 ± 4.1 (82.7 to 84.9)	0.73	0.78	0.50
End contact M_5 (%)	79.6 ± 5.9 (78.0 to 81.2)	78.7 ± 5.1 (77.4 to 80.2)	79.8 ± 4.9 (78.4 to 81.2)	0.67	0.92	0.56
End contact Mid foot (%)	57.5 ± 12.3 (54.1 to 60.9)	57.7 ± 12.1 (54.4 to 61.0)	57.0 ± 12.6 (54.1 to 60.5)	0.96	0.91	0.87
End contact H_M (%)	47.3 ± 11.0 (44.3 to 50.3)	46.1 ± 10.7 (34.1 to 49.1)	48.0 ± 11.2 (44.9 to 51.1)	0.56	0.59	0.85

End contact H_L (%)	40.3 ± 11.0 (37.3 to 43.3)	41.8 ± 9.4 (39.2 to 44.4)	40.9 ± 11.3 (37.8 to 44.0)	0.73	0.87	0.82

Abbreviations: Data is expressed as mean± SD, BFO; Before foot othoses, DFO; During foot orthoses, HCG; healthy control group.

Note: **#,** indicates variable analyzed by non-parametric tests (Wilcoxon and Mann–Whitney tests); *,Within- group differences; $, differences between HCG and BFO

Table 3.

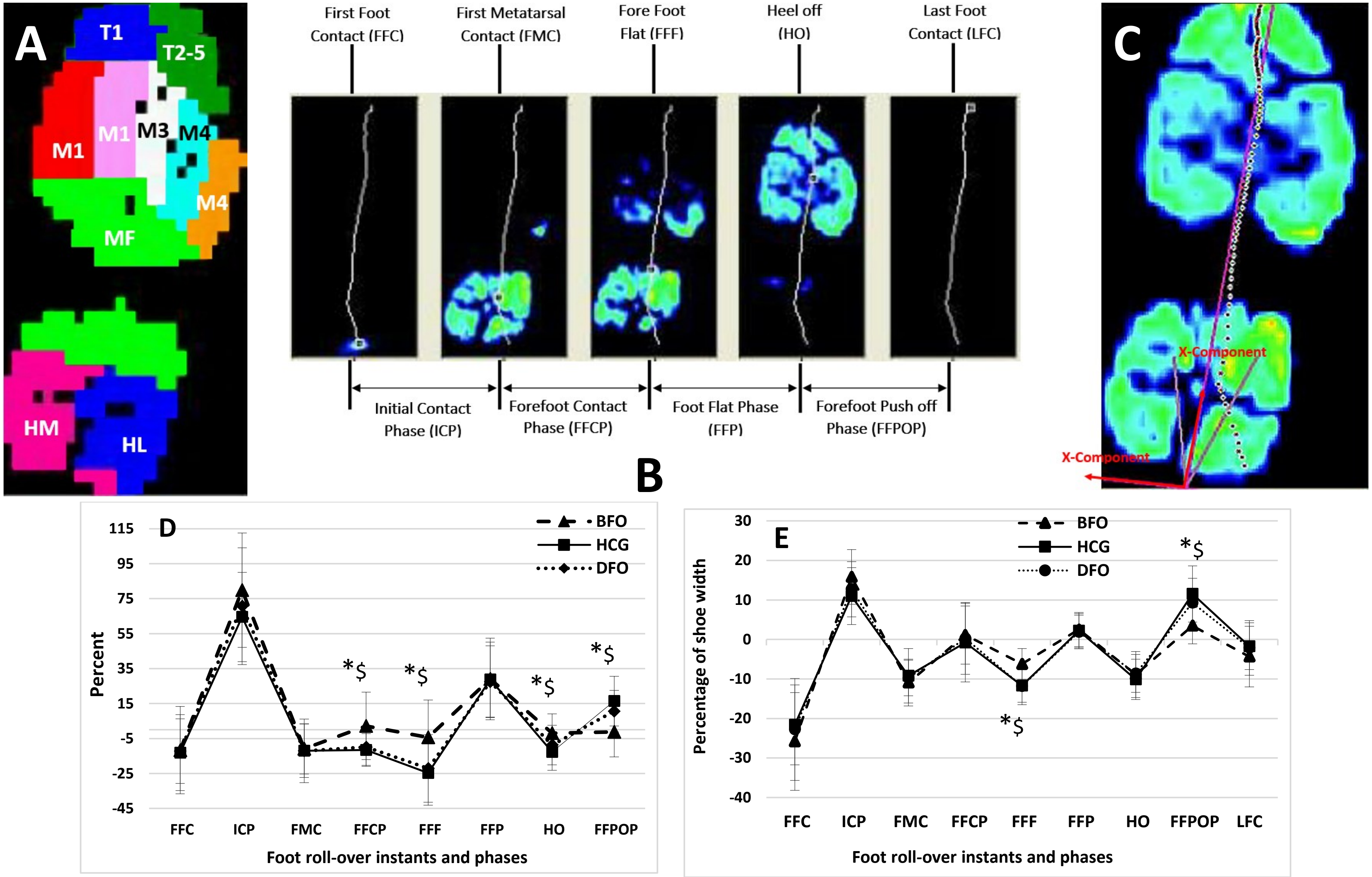
Peak pressure and absolute impulse underneath the ten anatomical areas between groups

Variables	BFO (n=50) Mean± SD (95% CI)	DFO (n=50) Mean± SD (95% CI)	HCG (n=50) Mean± SD (95% CI)	t test / Wilcoxon (p-value)	t test /Mann–Whitney (p-value) HCG W BFO	HCG W DFO
$PmaxT_1$ (N/cm^2)	18.9 ± 6.9 (17.0 to 20.8)	17.6 ± 5.3 (16.1 to 19.1)	16.9 ± 8.0 (14.7 to 19.1)	0.63	0.48	0.79
$PmaxT_{2\text{-}5}$(N/cm^2) #	9.1 ± 5.1 (7.7 to 10.6)	11.5 ± 6.2 (9.8 to 13.2)	11.2 ± 6.1 (9.5 to 13.9)	0.38	0.32	0.91
$PmaxM_1$(N/cm^2)	18.2 ± 4.8 (16.9 to 19.5)	17.2 ± 7.1 (15.2 to 19.2)	16.5 ± 5.9 (14.9 to 18.1)	0.70	0.40	0.78
$PmaxM_2$(N/cm^2)	22.8± 6.7 (20.9 to 24.7)	21.9 ± 8.5 (19.5 to 24.3)	20.4 ± 7.2 (18.4 to 22.4)	0.79	0.35	0.62
$PmaxM_3$(N/cm^2)	20.5±3.9 (19.4 to 21.6)	19.9 ± 5.4 (18.5 to 21.4)	20.5 ± 3.9 (19.4 to 21.6)	0.78	0.96	0.73
$PmaxM_4$(N/cm^2)	24.2 ± 5.5 (22.7 to 25.7)	24.1 ± 4.8 (22.8 to 25.4)	24.4 ± 4.0 (23.3 to 25.5)	0.97	0.91	0.87
$PmaxM_5$(N/cm^2)	18.3 ± 3.7 (17.3 to 19.3)	23.9 ± 7.3 (21.9 to 25.9)	23.5 ± 4.7 (22.2 to 24.8)	0.03*	0.003$	0.84
PmaxMid foot(N/cm^2)	12.1 ± 5.4 (10.6 to 13.6)	9.5 ± 3.4 (8.6 to 10.4)	7.6 ± 3.0 (6.8 to 8.4)	0.1	0.008$	0.11
$PmaxH_M$(N/cm^2)	18.7 ± 4.6 (17.4 to 20.0)	18.7 ± 2.4 (18.0 to 19.4)	18.2 ± 3.2 (17.3 to 19.1)	0.98	0.71	0.60
$PmaxH_L$(N/cm^2)	20.9 ± 4.6 (19.6 to 22.2)	20.9 ± 4.8 (19.6 to 22.2)	23.3 ± 4.4 (22.1 to 24.5)	0.97	0.16	0.15
$ImpulsT_1$ (Ns/cm^2)	1.7 ± 0.9 (1.5 to 1.9)	1.5 ± 0.7 (1.3 to 1.7)	1.5 ± 0.7 (1.3 to 1.7)	0.48	0.55	0.94
$ImpulsT_{2\text{-}5}$(Ns/cm^2)	0.7 ± 0.2 (0.6 to 0.8)	0.7 ± 0.2 (0.6 to 0.8)	0.8 ± 0.2 (0.7 to 0.9)	0.49	0.23	0.76
$ImpulsM_1$(Ns/cm^2)	1.8 ± 0.9 (1.6 to 2.0)	1.6 ± 0.6 (1.4 to 1.8)	1.5 ± 0.7 (1.3 to 1.7)	0.45	0.42	0.78
$ImpulsM_2$(Ns/cm^2) #	2.4 ± 1.3 (2.0 to 2.8)	2.3 ± 1.4 (1.9 to 2.7)	2.5 ± 1.2 (2.2 to 2.8)	0.81	0.79	0.58
$ImpulsM_3$(Ns/cm^2)	2.1 ± 0.6 (1.9 to 2.3)	2.1 ± 0.5 (2.0 to 2.2)	2.4 ± 1.0 (2.1 to 2.7)	0.77	0.26	0.31
$ImpulsM_4$(Ns/cm^2)	2.2 ± 0.9 (2.0 to 2.4)	2.6 ± 0.9 (2.4 to 2.8)	2.5 ± 0.9 (2.3 to 2.7)	0.25	0.37	0.68

ImpulsM_5(Ns/cm^2)	1.3 ± 0.6 (1.1 to 1.5)	2.1 ± 0.9 (1.9 to 2.3)	2.0 ± 0.8 (1.8 to 2.2)	0.006*	0.009$	0.78
ImpulsMid foot(Ns/cm^2)	0.9 ± 0.2 (0.8 to 1.0)	0.7 ± 0.2 (0.6 to 0.8)	0.7 ± 0.2 (0.6 to 0.8)	0.02*	0.002$	0.40
ImpulsH_M(Ns/cm^2) #	0.8 ± 0.3 (0.7 to 0.9)	0.9 ± 0.2 (0.8 to 1.0)	0.9 ± 0.2 (0.8 to 1.0)	0.84	0.57	0.71
ImpulsH_L(Ns/cm^2)	0.7 ± 0.2 (0.6 to 0.8)	0.8 ± 0.3 (0.7 to 0.9)	0.9 ± 0.2 (0.8 to 1.0)	0.4	0.01$	0.13

Abbreviations: Data is expressed as mean± SD, BFO; Before foot otrhoses, DFO; During foot otrhoses, HCG; healthy control group.

Note: **#,** indicates variable analyzed by non-parametric tests (Wilcoxon and Mann–Whitney tests); *,Within- group differences; $, differences between HCG and BFO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First Foot Contact (FFC)
First Metatarsal Contact (FMC)
Fore Foot Flat (FFF)
Heel off (HO)
Last Foot Contact (LFC)
Initial Contact Phase (ICP)
Forefoot Contact Phase (FFCP)
Foot Flat Phase (FFP)
Forefoot Push off Phase (FFPOP)
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Foot roll-over instants and phases
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Foot roll-over instants and phases
FFC ICP FMC FFCP FFF FFP HO FFPOP LFC
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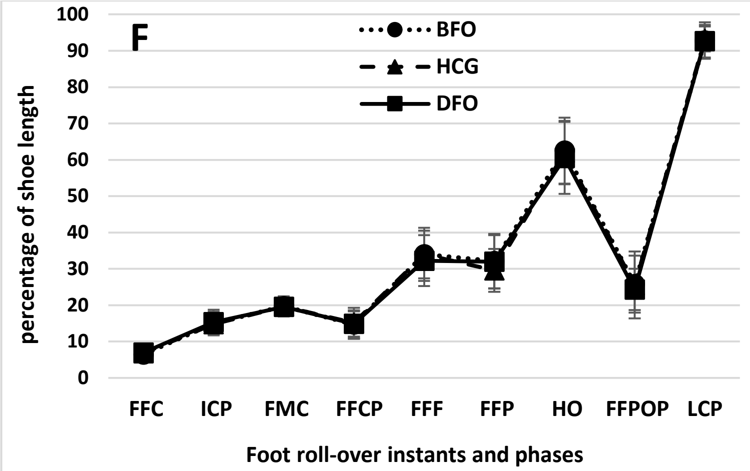
F
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percentage of shoe length
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FFPOP
LCP
Foot roll-over instants and phases

Fig. 1. **(A)** The location of the 10 anatomical areas: MH: medial heel; HL: lateral heel; MF: midfoot; M1, M2, M3, M4 and M5: metatarsal areas I–V; T1: hallux; T2-5: toes 2–5; **(B)** Illustration of the five distinct instants and four phases of foot roll-over; **(C)** The X-component (medio-lateral) and Y-component (anterior- posterior) of the center of pressure (Footscan software 7.0 Gait 2nd Generation, RsScan International); **(D)** The medio-lateral pressure ratio, course of pressure distribution (with SD) underneath the forefoot at four instants (FMC, FFF, HO, and LFC) and during four phases of foot roll-over (ICP, FFCP, FFP, and FFPOP). A positive ratio indicates a medial pressure distribution, and a negative ratio indicates a lateral pressure distribution. Ratio= [(T1 + M1 + HM) - (HL + M3 + M4 + M5)] ×100/ (sum of the pressure underneath all areas); **(E)** Scaled X-component (medio-lateral) of the center of pressure at the five instants (FFC, FMC, FFF, HO, and LFC) and during the four phases of foot roll-over (ICP, FFCP, FFP, and FFPOP). The X-component was scaled as percentage of shoe width and is positive when it is positioned medially of the heel-M2 axis and negative when it is positioned laterally; **(F)**. Scaled Y-component (anterior-posterior) of the center of pressure at the five instants (FFC, FMC, FFF, HO, and LFC) and during the four phases of foot roll-over (ICP, FFCP, FFP, and FFPOP). The Y-component was scaled as percentage of shoe length; its position relative to heel was reported.

Abbreviations: BFO, before foot orthoses; DFO, During foot orthoses; HCG, healthy control group; FFC, first foot contact; FMC, first metatarsal contact; FFF, forefoot flat ; HO, heel off; LFC, last foot contact, ICP, initial contact phase; FFCP, forefoot contact phase; FFP, foot flat phase; FFPOP, forefoot push off phase; *, Within- group differences (i.e. between BFO and DFO); **$**, between group differences (i.e. between HCG and BFO)